

Shallow Water Acoustic Propagation in Anisotropic Scattering Environments: Student Support

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LONG TERM GOALS

The long-term goal of this research is to improve our ability to model and predict VLF acoustic propagation in shallow water with particular emphasis on the range dependence of the medium and the geoacoustic properties of the bottom, and to quantify the various factors affecting the overall acoustic energy budget in shallow water propagation.

OBJECTIVES

Our scientific objectives are to incorporate the effects of sediment anisotropy, strong sediment attenuation, and the effects of both deterministic and stochastic medium properties into a local coupled mode propagation model, and to develop accurate theory and robust numerical algorithms for the shallow water propagation problem.

APPROACH

We are using an approach based on coupled local modes to carry out a systematic study of the effects of scattering, normal dispersion, anisotropy and intrinsic attenuation on a propagating shallow water acoustic signal with strong bottom interaction. The coupled mode theory is developed from the first order equations of motion for the stress and displacement rather than from the second order equations for a velocity or displacement potential. The later approach introduces coupling coefficients depending on the second-order derivatives with respect to the range coordinate of the local mode functions. These second-order coupling coefficients are an artifact of the formulation, and not present in the coupled mode theory based on the first order equations of motion.

WORK COMPLETED

We have made significant progress towards understanding the effects of sediment anisotropy on mode coupling in a range dependent shallow water waveguide. The modes in a purely fluid waveguide are intrinsically ordered by the number of zero crossings in the vertical direction. The number of zero crossings also correlates directly phase velocity. Modes with larger numbers of zero crossings have a higher phase velocity. In a waveguide with an elastic bottom, the presence of shear complicates the mode ordering. The number of zero crossings may not indicate the mode order. However, the modes can still be ordered by phase velocity. In a shallow water waveguide with an isotropic or transversely

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14. ABSTRACT The long-term goal of this research is to improve our ability to model and predict VLF acoustic propagation in shallow water with particular emphasis on the range dependence of the medium and the geoacoustic properties of the bottom, and to quantify the various factors affecting the overall acoustic energy budget in shallow water propagation.					
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isotropic bottom, SH is decoupled from the P-SV motion, and the SH component does not participate at all in the propagation of the water borne acoustic modes. However, in a waveguide with a more generally anisotropic bottom, the P-SV modes and the SH modes are no longer independent, and there can be significant energy in the quasi-SH, which must be taken into account even for the water-borne acoustic modes, if they have any significant bottom interaction. Transversely isotropic media have a vertical symmetry axis. In more general media with an arbitrary symmetry axis, the identity of individual modes can be exchanged as the symmetry axis rotates. This can occur due to bathymetry or aligned cracks in the sediments, for example. If the bottom is anisotropic, and the medium is range dependent, how do we order the modes to be used in a mode coupling computation? Our latest results address this question, and are discussed in the next section. This work has been submitted for publication (Soukup and Odom, 2001). The derivation of a number of technical results regarding the propagator is range dependent fluid-elastic waveguides along with a Feynman diagram representation of the derivation of the Dyson and Bethe-Salpeter equations for the propagator in a range dependent fluid-elastic medium was completed and submitted last year. The paper has been accepted for publication (Park and Odom, 2001).

RESULTS

Strong range dependence in a shallow water waveguide will couple modes together, resulting in dispersion of a signal because of the differing group velocities of the various modes. In isotropic media such as fluids and isotropic elastic bottom material, and in transversely isotropic (TI) elastic media, the mode coupling is mostly dominated by the $1/\Delta k$ term in the mode coupling matrix B_{qr} . The result is that the strongest interactions occur between nearest neighbors in phase velocity, and the coupling matrix is nearest neighbor dominant with the strongest interactions closest to the diagonal (Odom et al. 1996). If the bottom sediments are layered in such a way so that the normal to the layering is not also normal to the water surface, the symmetry of the TI medium is broken and the anisotropy of the bottom sediments takes on a more general form. The effects on a bottom interacting propagating acoustic signal can be significant.

Figure 1 illustrates the effect of rotating the symmetry axis away from the vertical of an initially TI medium. The upper left diagram in Figure 1 is a modal dispersion diagram. Modal phase velocity is plotted as a function of symmetry tilt axis for a model consisting of a 100m water layer over an anisotropic bottom sediment package. If the bottom sediments were isotropic, the lines across the figure would be perfectly straight. The modal phase velocities would be insensitive to direction, and the phase would be constant with respect to any angle. However, if the bottom sediments are anisotropic, modal phase velocities vary by as much as 50 m/s for this model. The frequency is 50 Hz. Shown in the upper right corner of Figure 1 is the same dispersion diagram with the modes of “constant identity” overlayed in red. Constant mode identity is tracked by doing a cross-correlation between modes. The initial identity is determined for the transversely isotropic medium for which the angle out of the x-z propagation plane $\phi=0$. The SH and PSV modes are not coupled together for such a medium. As the symmetry axis is rotated from the vertical $\theta=0^\circ$ to the horizontal $\theta=90^\circ$, SH and PSV modes maintain their original identity. For the case $\phi \neq 0$ the modes do not maintain their identity as the symmetry axis is rotated from vertical to horizontal. As the symmetry axis is rotated, a cross-correlation is carried between the mode for which $\phi=0$ with the mode with the same θ , and, in this case, $\phi=10^\circ$. Two modes that started out as quasi-SH and quasi-PSV, respectively, may switch identity. Modes of constant identity are tracked in the upper right figure by following the black or red branches.

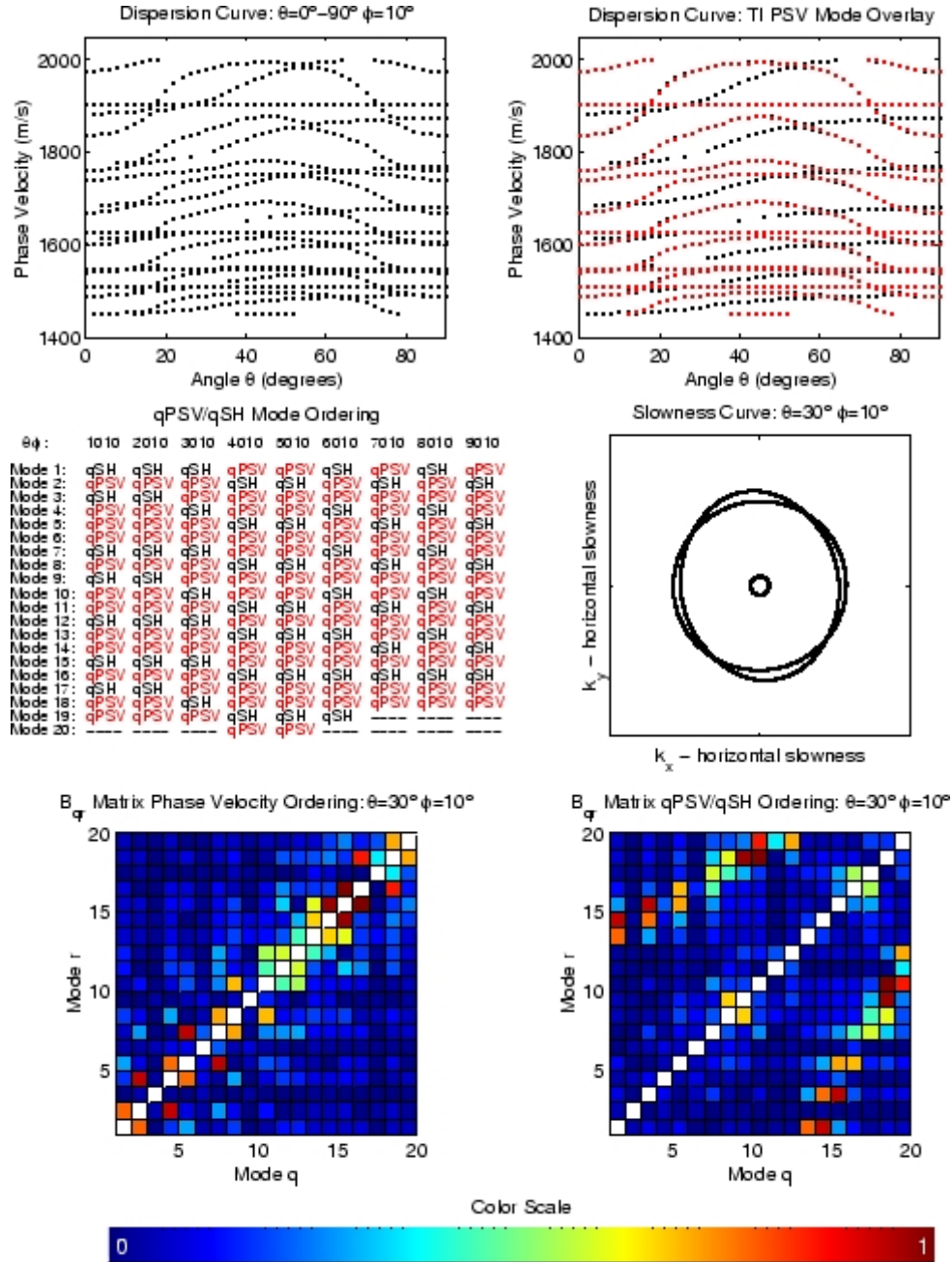


Figure 1. This figure shows a dispersion curve for an anisotropic fluid-elastic medium (upper left corner); dispersion curve with the transversely isotropic overlay, showing modes of constant type (red is quasi-PSV and black is quasi-SH (upper right); mode table which shows mode type change with symmetry axis angle – red for quasi-PSV and black for quasi-SH (middle left); slowness curve in the horizontal plane – larger figures are the two quasi shear slownesses, and the smaller central circle is a near pure longitudinal slowness curve (middle right); mode coupling matrix B_{qr} with modes ordered by phase velocity (lower left); and, mode coupling matrix B_{qr} with modes ordered by type, quasi-PSV first followed by quasi-SH (lower right). The model is a 100m water layer over anisotropic sediments. The frequency is 50 Hz. The two crucial points are that: (1) the modes should be ordered by phase velocity, which shows the nearly nearest neighbor interactions for the coupling, and (2) there is strong quasi-PSV to quasi-SH coupling indicating that if the medium is range dependent and the bottom is anisotropic SH cannot be ignored.

The middle figure on the left is another presentation of the result shown in the upper right. The identity of an individual mode can be tracked by moving from left to right in the diagram. For example, mode 1 starts as a quasi-SH, becomes a quasi-PSV for a symmetry angle around 40° , then oscillates between quasi-SH and quasi-PSV between 60° and 90° .

The slowness curve in the middle right of Figure 1 shows how the slowness varies about the vertical medium axis in the x-y plane for the anisotropy symmetry axis inclined at 30° from the vertical. The two larger figures are the quasi-shear surfaces, and the small circular curve is a nearly pure longitudinal wave slowness surface.

The lower left plot is the scattering matrix B_{qr} for which the modes have been ordered by phase velocity without regard to type. Notice that the coupling is all nearest-neighbor in phase velocity. This is good. This means we have properly ordered the modes. Since most of the coupling is almost nearest neighbor, this has significant implications for the efficient computation of coupled mode acoustic signals.

The lower right plot is again the coupling matrix B_{qr} , but with the modes ordered by type, either quasi-PSV or quasi-SH. The plot is ordered so the quasi-PSV modes come first followed by the quasi-SH. What can be seen from this is that although the coupling is almost nearest-neighbor in phase velocity, there is strong coupling between quasi-SH and quasi-PSV, and relatively weak coupling to modes of like type. This is an important result with implications for shallow water propagation. If the medium is range dependent, and the sediments are anisotropic, SH is very important, and really cannot be ignored.

IMPACT/APPLICATIONS

Highlighting the importance of sediment anisotropy in mode coupling and signal loss is an important step in the understanding of acoustic propagation in complicated heterogeneous waveguides. This research is directly applicable to predicting the effect of a complicated shallow water environment on the acoustic field.

An important application to another field of the theoretical results we have derived is the generation of oceanic T-waves. The modal scattering theory of Park and Odom (1999) was used to show that modal scattering from a sloping bottom or seabed roughness can excite the low order acoustic modes known to carry the T-waves (Park et al., 2001). This application was funded under the National Ocean Partnership Program (NOPP).

TRANSITIONS

Modal methods for modeling in random range dependent shallow water waveguides should provide important constraints on the most significant waveguide properties affecting propagation at low frequencies.

RELATED PROJECTS

Our research is directly related to other programs studying surface, volume and bottom interaction effects, including 6.2 and 6.3 efforts to quantify bottom backscatter and bottom loss effects in littoral regions.

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